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Modeling the effect of microneedle array spacing on insertion force

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Effective and precise insertion of microneedles into skin remains an important issue of discussion for optimal design and fabrication of microneedles. In this context, predictive analysis of the force required to insert microneedles into the skin has been reported to be important1,2. In addressing this issue, we propose to present a series of mathematical models which relates the mechanical properties of the skin with the geometry and distribution of microneedles in an array. In particular we investigate the effect of interspacing on the force required to pierce the skin and present a theoretical model to represent this validated by experimental results. The presented model takes the approach of separating the individual forces acting between the microneedle and the skin and drawing analogy between a beam on an elastic foundation and mechanism of needle insertion. Theoretical analysis carried out indicates a decrease in insertion force as interspacing between microneedles increase. For a specified skin type as interspacing at microneedle tip increased from 50 μm to 150μm, the force to pierce skin per microneedle decreased from 0.029N to 0.028N. This dependence of insertion force on microneedle interspacing seizes to exist at higher interspacing above 150μm for the specified skin type; thus, indicating that interspacing between microneedles has an effect on insertion force only at small interspacings. This was also the same pattern observed from finite element simulations of microneedle insertion into skin at various interspacing. Experiments on porcine skin are used to validate the developed model. The force required to insert microneedles into porcine skin was determined using a force testing station and insertion occurred at 0.5 and 0.1mm/s1. Experimental values gave insertion force values of 0.030N and 0.0216N respectively for 30μm interspacing at insertion speeds of 0.5 and 0.1mm/s1. At interspacing of 600μm the insertion forces were 0.028 and 0.0214N respectively1, thus confirming the theoretical model and finite element analysis. Such models are significant in the development of effective microneedle systems based on performance prediction taking into consideration the biomechanics of the skin.

References
